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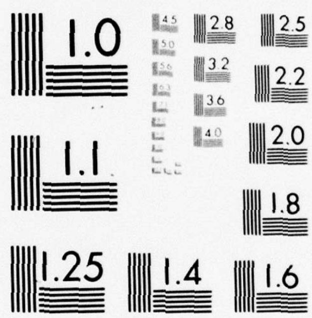

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SPECIFICATION OF GEOSYNCHRONOUS PLASMA ENVIRONMENT

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1 February 1977

Final Report for Period 1 June 1976 - 30 November 1976

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AIR FORCE GEOPHYSICS LABORATORY
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(19) REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (18) AFGL-TR-77-0031	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) SPECIFICATION OF GEOSYNCHRONOUS PLASMA ENVIRONMENT.		5. TYPE OF REPORT & PERIOD COVERED Final Report. 1 June 1976 through November 30, 1976,
		6. PERFORMING ORG. REPORT NUMBER (30)
7. AUTHOR(s) (10) Sherman E. DeForest		8. CONTRACT OR GRANT NUMBER(s) (15) F19628-76-C-Ø214
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Pure and Applied Physical Science University of California, San Diego La Jolla, California 92093		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F (16) 76610601 (17) 06
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/C. Pike/PH		12. REPORT DATE (11) 1 February 1, 1977
		13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 33p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data from UCSD plasma instruments on the ATS 5 and 6 satellites has been studied to specify the geosynchronous plasma environment as it affects electrostatic charging of spacecraft. The emphasis of the initial study has been primarily to service the needs of the design engineer; while simultaneously establishing the context in which a more general model could be developed. The report includes an environmental specification plus a review of geosynchronous plasma and wave phenomena.

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TABLE OF CONTENTS

FOREWORD

This report covers work supported by Air Force contract No.: F19628-76-0214 during the period June 1, 1976 through November 30, 1976. The work was also supported in part by DNA on a sub-contract from System, Science, and Software of La Jolla, contract No.: S3-S-57191. Interested readers are referenced to the S3 report, "A Preliminary Specification of the Geosynchronous Plasma Environment."

The main part of the work presented here was given at the Spacecraft Charging Technology Conference in Colorado Springs, 1976, and in an augmented form will appear in the proceedings of that conference. See also the panel discussion which followed the main conference.

Work is continuing on this project with more emphasis on cataloging specific types of events and their relative occurrences.

This contract has resulted in, or partially supported, three technical papers, and several presentations. Perhaps more importantly, under this contract data has been distributed to many potential users including AFGL, NASA Lewis Research Center and Jet Propulsion Laboratory. Close contact has been maintained with the staff of AFGL, and they have benefited significantly from scientific discussions with UCSD personnel.

I. GENERAL DISCUSSION OF THE PROBLEM

Spacecraft charge up when immersed in a plasma. Different surfaces can charge to different potentials and cause breakdowns which can have a variety of effects. A partial list of proven or suspected results of spacecraft charging includes:

1. Creation of spurious logic signals
2. Destruction of electronic components
3. Degradation of thermal control surfaces
4. Degradation of optical surfaces
5. Degradation of solar cells
6. Creation of EMI
7. Compromising environmental measurements

The basic reasons why surfaces in a plasma should charge up are reasonably well understood (see references in Section VI). The detailed understanding of how a particular spacecraft will react to a given environment is, however, a very difficult problem which is only now yielding to the efforts of several top groups around the world. The theory of spacecraft charging is beyond the scope of this report. The interested reader is referred to the literature. Suffice it to say here that knowledge of the detailed character of the natural plasma is necessary to predict potentials induced on arbitrary surfaces. Therefore, we have the task of using the available environmental measurements to assemble a preliminary environmental specification. The data base consists of the measurements made by the UCSD plasma instruments on board ATS-5 and ATS-6. This preliminary environmental specification should be suitable for several purposes.

1. Aid spacecraft designers
2. Provide input to groups doing theoretical studies, and
3. Provide the basis for a firmer environmental atlas to be completed at a later date.

The potential users of an environmental specification are:

1. Air Force
2. NASA
3. DNA
4. Commercial sector

The Air Force is primarily interested in solving the problem of environmentally induced spacecraft operating anomalies as quickly and as cheaply as possible. A secondary goal is to make sure that no new charging problems occur on new spacecraft. NASA is properly interested in the same problems, but in addition would like to do more "science" in understanding the basic phenomena. DNA is primarily interested in having a good model of the natural environment to use as the input boundary condition on large machine codes to study space vehicle responses to artificially enhanced environments. The commercial sector has much the same interest as the Air Force. They want to be able to build the best possible spacecraft for a given dollar constraint. All these needs can not be met by one table of numbers or equations.

Finally even the ATS data is insufficient to do a complete environmental specification -- even in principal. These instruments do not have mass resolution capability, and their time resolution is not sufficient to investigate certain transient phenomena. Other people have realized this and supported the SCATHA concept of launching a spacecraft with the specific charter of investigating spacecraft charging. We will be able to update and improve our environmental specifications periodically but we will need SCATHA data to really complete the job.

II. NATURE OF THE ENVIRONMENT

The plasma at geosynchronous orbit as we now understand it is a dynamic medium with much greater variation on a daily basis than the variation in regular atmospheric weather. Essentially all major parameters can vary over at least two orders of magnitude in one day. If we expand the time base to a year, we can expect to spend about 3% of the time in a completely different regime -- the magnetosheath. If we expand the time base to periods of 5 - 10 years, we can see several other relatively rare phenomena such as unshocked solar wind, oscillating flow fields (± 200 Km/sec), extremely intense, localized plasma injections, and intense field aligned fluxes. These rare events might not occur in the lifetime of a given spacecraft, but could severely damage it if they did occur.

A major goal of the proposed follow-on study is to assess the probability of encountering these rare phenomena as a function of general activity and orbital position. For the present we must be content with the description of plasma injection presented in Section VI with sufficient margin to allow for unusual cases.

III. APPROACH TO SPECIFICATIONS

For historical reasons, this effort actually started at the request of DNA because they wanted a reasonable, but not necessarily complete environmental specification to use in the large computer codes which study system generated electro-magnetic pulse. This is a rather sophisticated use of the data, and the approach was adopted of using actual measurements of the plasma from selected days. For technical reasons, the prime data base for this was ATS-5. The results are presented in the S3 report mentioned above.

This approach was expanded and used as a first cut at establishing the meteorological atlas of geosynchronous orbit that the Air Force wanted. However, communications with potential users have strongly indicated that this approach of supplying average data tapes suitable for input to computer programs is much too sophisticated. Some users would prefer only to be given maximum density and temperature of the natural plasma to use to design spacecraft. Therefore the original approach, although superior in terms of providing a better picture of the environment, has been temporarily suspended to do the work presented in Section VI which has as its output a small set of numbers for engineering use. The simplification of an environment that can be described by 17 independent variables to two or three fixed numbers is drastic, but useful.

These simplified results were obtained by considering all plasma injections that occurred in one year in the vicinity of ATS-5. No magnetic or electric fields were considered. No local time dependence was considered. The plasma was assumed isotropic. No attempt was made to estimate the population of heavy ions. That is, all ions are simply assumed to be protons (see Figure 10, page 26 for results).

During the follow-on effort this type of approach will be expanded a bit to include categorization of charging events on ATS-6 and encounters with low-energy plasmas. Simultaneously we will continue to make the more complicated magnetic tapes available to model makers and other interested users.

Eventually these different approaches will be collected into a grand environmental atlas which will contain all the average curves as well as the sample days. In this form, the atlas can easily be augmented to include new knowledge such as the results from the GEOS or SCATHA satellites.

IV. CONTROL OF POTENTIAL

To the extent possible, we intend to catalog the response of different materials to the plasma environment. During this contract period, we have studied particles of seven different types which have originated on ATS. These include the ubiquitous photoelectrons and the mysterious particles which have been unambiguously traced to a rotating sensor on a nearby instrument. The white paint on the sensor has charged up differentially with respect to spacecraft ground and emits particles under certain, as yet not understood, conditions.

This study of locally produced particles is still in its infancy and we will not be ready to publish results for several months.

In cooperation with NASA Lewis Research Center and GSFC, we are currently studying periods of active control on both ATS-5 and ATS-6 by means of deliberate particle emission. The initial results of this study have been presented at the Spacecraft Charging Technology Conference in Colorado Springs, and will appear in the proceedings.

Both the study of locally produced particles and active control of potentials are important, but peripheral to the main thrust of this reporting period. Therefore they are mentioned here only as work in progress.

V. STATUS OF DATA

The ATS data is available in several formats. The formats available include:

1. Standard 24 hour-spectrograms
2. Cataloged special purpose spectrograms
3. Line plots (approximately 1 minute each)
4. Tables of plasma integrals (ATS-5 only)

Printouts of special data as well as plots of spectra averaged over arbitrary periods can be produced with a minimum of effort.

For both spacecraft the on-board magnetometer is also available on the data tapes. Other useful data such as eclipse times and ion gun firings are also available.

It should be noted that for reasons of economy, such items as line plots do not exist for all of the data and must be generated as needed for special studies such as this one. Every effort is made to keep the various outputs in a few standard forms in order to reduce the duplication of effort between studies.

VI. RESULTS

The most convenient way to present the results to date is to present the written form of the oral presentation given at the Spacecraft Charging Technology Conference, as amended to reflect what was learned at the meeting.

1.0 INTRODUCTION

The scope of this paper is two-fold:

1. Present a picture of the magnetosphere about geosynchronous orbit (GSO) to the non-specialist, and
2. Introduce a preliminary model which should be of use to spacecraft designers as well as magnetospheric researchers.

The emphasis of both the environmental discussion and the model presentation is to give information to investigators who are not necessarily engaged in magnetospheric research.

In designing this type of presentation, one must first ask, "why is it important?", and "who is the audience?". For the purposes of this presentation, we assume that the importance of the plasma environment is due to the fact that it interacts with spacecraft surfaces to produce electrostatic charging. We will give only nodding recognition to the important and exciting geophysical implications of the plasma dynamics at GSO. Similarily, we will assume that a large fraction of the intended audience will not be intimately familiar with the specialized jargon of the magnetospheric physicist.

Finally, we acknowledge that this paper presents work in progress and that the many gaps in our understanding of the conditions of GSO will not be closed until after the GEOS and SCATHA missions are successfully completed.

The magnetosphere is a very complicated place, and GSO is located at the boundary of several distinct plasma regions. As can be seen from Figure 1, which is a new version of a much used figure by W. Heikkila, the low altitude plasma is a low-temperature, relatively high-density region, called the plasmasphere, (a temperature of a few electron volts and densities of 10-1000 particles/cm^3, see Chappell)[1]. Higher altitude plasma in general is much hotter and less dense (1000's of electron volts and 1 particle/cm^3, see DeForest and McIlwain,)[2]. This is generally called the plasmasheet. Much of the physics governing spacecraft charging at GSO is determined by the interplay of these two regions as they move in and out past a space vehicle.

During geomagnetically active times, all the boundaries shown in Figure 1 tend to move inwards. This means that the magnetopause can occasionally pass inside geosynchronous orbit and expose a vehicle there to the magnetosheath particles.[3,4] Russell (private conversation) has estimated that approximately 3% of the time a vehicle at geosynchronous orbit will be in the magnetosheath. At least once, ATS-5 was actually exposed to the unshocked solar wind.[5] No operating anomalies

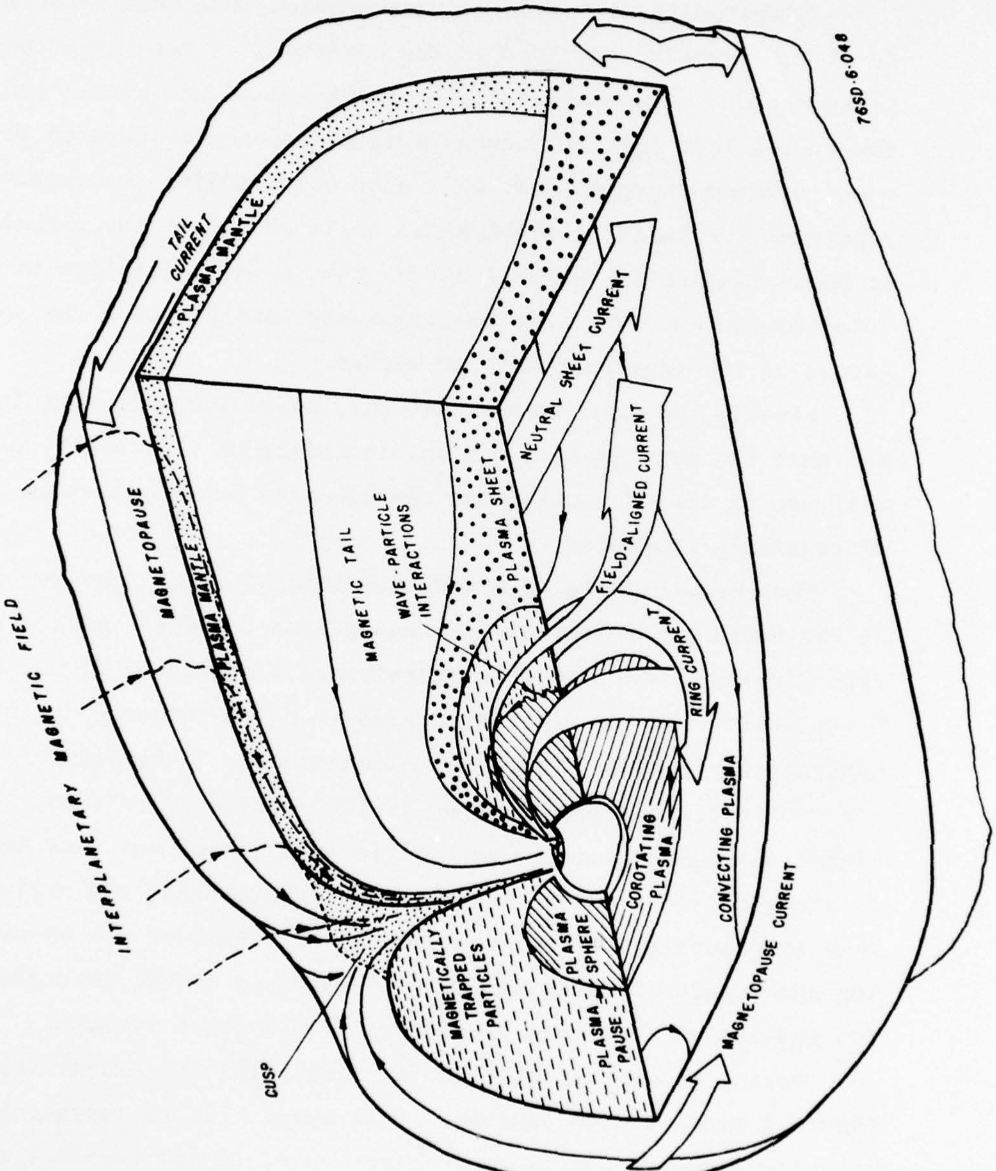

Figure 1. Magnetosphere (Heikkila)

are known to be associated with these transitions. Since the characteristics energies of the magnetosheath particles are much lower than those of the plasmasheet, no further discussion of these regions will be presented here. However, a complete model must take these regions into account.

2.0 GENERAL MORPHOLOGY AND DYNAMICS

2.1 GLOBAL VARIATIONS

Although the theory of plasma dynamics in the magnetosphere is still being developed, rather simple considerations can be used to predict that the plasmasphere should not be spherically symmetrical at all, but should bulge on the dusk side. This has been shown repeatedly by both ground-based and in situ measurements.[1,6,7] Furthermore the boundary, called the plasmapause, moves inward with increasing activity. As a general rule, features of the plasmasphere co-rotate or nearly co-rotate with the earth until they dissipate and can no longer be observed. Also as a general rule, the density decreases strongly with increasing equatorial altitude. These rules are very approximate since we are really discussing a type of weather.

Since the plasmaspheric particles are not very energetic, their motions will be predominantly determined by local electric fields. This is contrasted with the more energetic plasmasheet particles which tend to be dominated by magnetic effects.

This difference in the dynamics of the two populations also determines certain differences in the nature of their spectra. Plasmasheet particles appear suddenly in injection events[2] which have a one-to-one correlation with ground based substorms.[8,9] After injection, electrons gradient drift to the East and the ions gradient drift to the West. The speed of the drift is proportional to the energy of the particle. At lower energies, these motions get modified by electric field effects. The net result is that even though the plasma is Maxwellian at the injection, the nature of the particles that will strike a vehicle surface depends strongly on where that vehicle is with respect to the location of the injection. In general, a vehicle will encounter high fluxes of electrons between midnight and dawn. This is simply because they move that way shortly after injection. Contrariwise, excess energetic ions can be encountered in the pre-midnight sector. This latter situation has not proven to be as hazardous to spacecraft operation as the former. Therefore, we will tend to emphasize the electron dynamics in what follows.

The electric fields present at geosynchronous orbit have not been measured directly, but they are of the order of MV/m. From this and the condition stated above, one can conclude that gross charge neutrality always holds for the plasma. That is, after an injection, a polarization field is set up as the particles try to gradient drift apart. This field then affects the sea of low-energy particles in such a way as to reduce it.

The magnetic field has been measured at GSO by a variety of space vehicles and is, therefore, reasonably well-known.

Using plasma data from ATS, McIlwain [10] derived a best fit static electric field for the magnetosphere after an injection, (Note: actual fields during injection are undefined and during very quiet times the field at GSO is much smaller than shown here. Therefore this field is at best a useful approximation) as shown in Figure 2. Note the closed field lines which bulge on the dark side. This delimits the approximate plasmapause.

With both electric and magnetic fields in hand Mauk and McIlwain[11] could go one step further and show that injections occur with a sharp well defined spiral boundary. This is shown in Figure 3. This boundary moves in and out with geomagnetic activity in a quantitative way. Confirmation of the existence of this boundary has been provided by Konradi, et al[12] in their studies of Explorer 45 data.

This boundary can be used to predict approximately where a space vehicle will first encounter hot electrons and, thus, might become a useful tool for operational spacecraft. However, the calculations needed to make predictions cannot now be made on-line.

2.2 TIME VARIATIONS

Substorms (or plasma injections) tend to occur every three hours approximately. Only rarely will a period as long as a day go by without significant activity.[13] The giant storms which attract popular attention

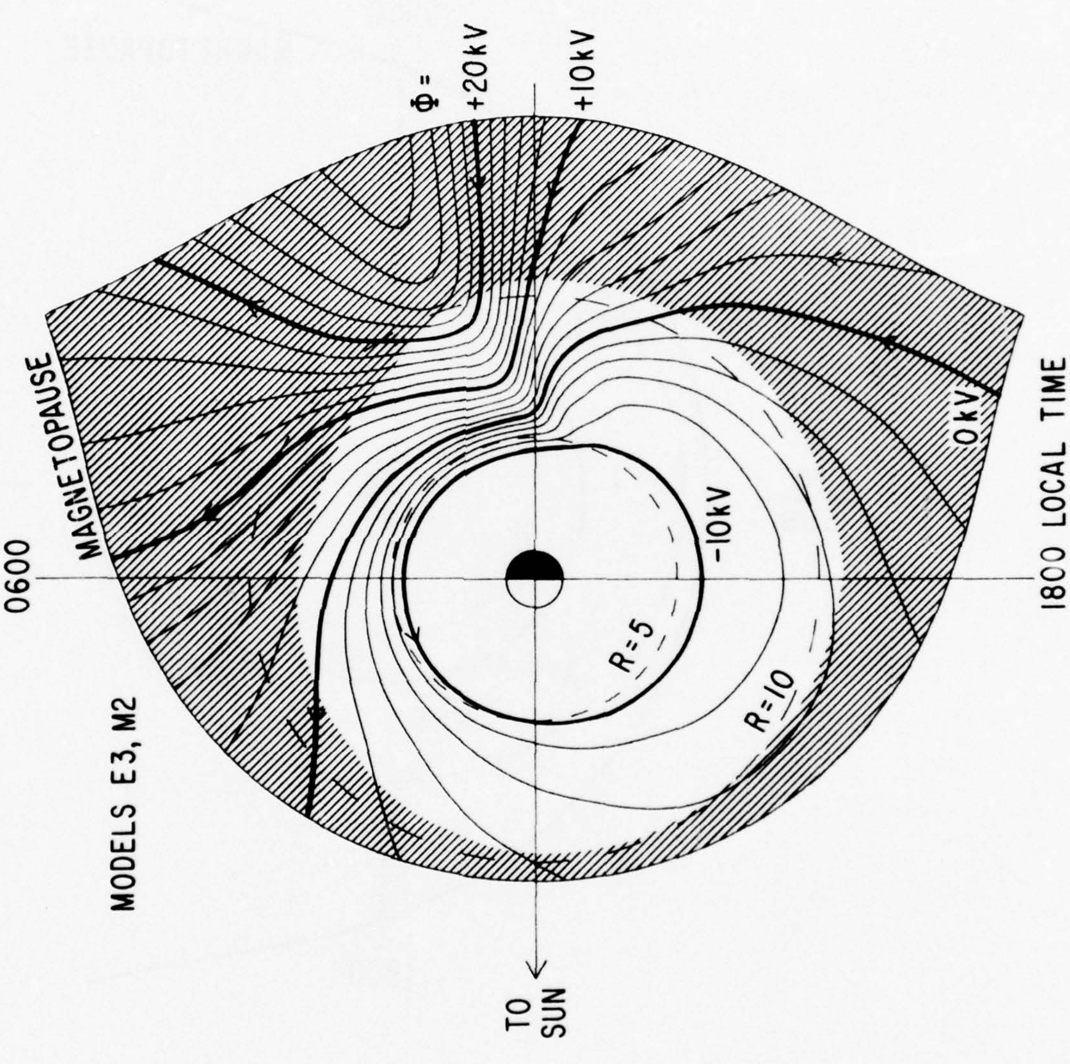

Figure 2. Electric Fields (McIlwain)

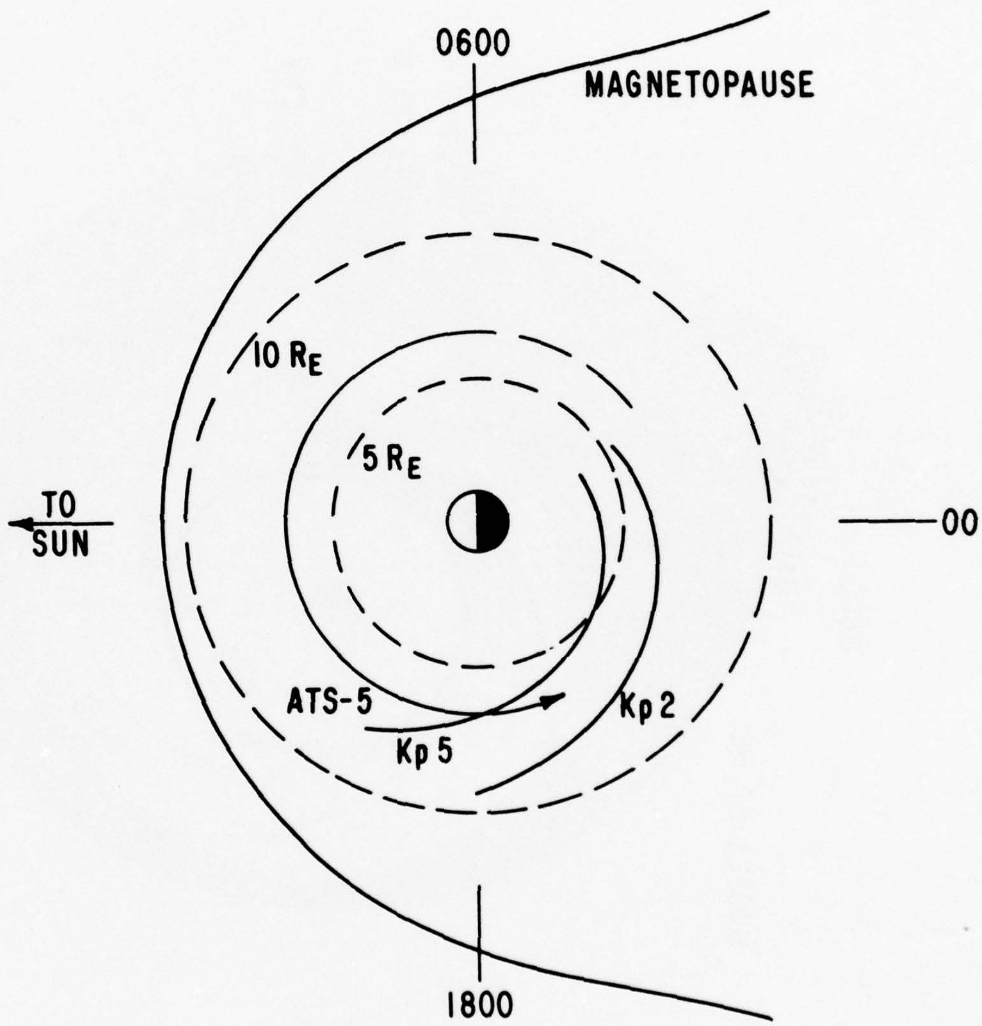

Figure 3. Injection Boundary (Mauk and McIlwain)

by creating bright auroras at latitudes which are heavily populated and by affecting radio transmissions are composed of several substorms occurring in so rapid a succession that the magnetosphere does not have time to recover between them. Then each successive injection delivers particles to lower magnetic shells. Both periods of extreme quiet and extreme activity can be predicted with some accuracy by solar observations. The same is not true of substorms. Whipple (this conference) has stated that he believes that a suitable precurser can be found for substorms, and Rostoker[14] has postulated a certain type of wave activity before a substorm based on observations from standard ground-based magnetometers.

On the longer time scale, the frequency of all kinds of geomagnetic activity is determined by the solar cycle and we are approaching a solar maximum so we can expect more activity in the next couple of years. Recent work[15] has shown that there might be periods when the sun is very quiet and no sun spots or auroral activity is seen for tens of years. This is current research, but we are unlikely to enter such a quiet condition in time to affect design of present day spacecraft.

Time variations with periods much shorter than time periods associated with substorms are probably not global in nature, but localized events as discussed in the next section.

3.0 DETAILED OBSERVATIONS AND EVENTS

3.1 OBSERVATIONS

The direct measurements of the plasma distribution function at GSO are very limited. In spite of the great popularity of this orbit for operational spacecraft, only three semi-research oriented space vehicles have flown there (ATS-1, 5 & 6). Many spacecraft have made cuts through this region, but since these cuts come at large intervals (e.g. 2 days) and last for only minutes, they do not allow detailed studies. Low altitude-high inclination vehicles can detect particles that will traverse the GSO equatorial region, but uncertainties about the proper mapping make inferences difficult.

Although a low-energy instrument was carried on ATS-1,[16] it did not have the energy resolution necessary to measure the spectra. This means that most of our information comes from the UCSD instruments on ATS-5 & 6. We eagerly await the observations of GEOS (launch in Spring 1977) and SCATHA (launch in January 1979) to augment the data base. Of particular interest will be the mass spectrometer results and the various field measurements.

3.2 WAVES

Many classes of waves exist in the magnetosphere. Some have periods of several minutes. Some have millisecond periods. Some theorists would even consider substorms a wave phenomena.

It is far beyond the scope of this report to review the types of waves that have been observed. However, we will present a single example of a type of wave which might be able to affect spacecraft operations. This is a Pc4 wave of the type which has been seen on geosynchronous spacecraft equipped with magnetometers.[17] The work shown here, which is taken from a paper being prepared by Cummings, DeForest, and McPherson for submission to the Journal of Geophysical Research, is the first observation when both particle and field measurements were available. The spectrogram in Figure 4 shows the modulation produced in a detector looking West during the wave event (readers unfamiliar with spectrograms should refer to the description in DeForest and McIlwain[2]). Another detector faced East, and a third looked radially outward. This allowed us to calculate the flow velocity implicit in the modulations. From that information and the known magnetic field, the complete wave can be described. (Strictly speaking, only the component of flow in the plane of the detectors is measured.)

The part of this type of wave which concerns the spacecraft designer is that the modulations in Figure 4 represent flows of 150-200 Km/sec with a period of 150 seconds. By comparison, a 50 eV proton has only a speed of 100 Km/sec. This means that first one side of the space vehicle then the other will experience a depletion of the lowest energy particles. We do not yet know what effects this might have.

We expect with the launch of SCATHA to detect waves interactions all the way up to VLF frequencies. Such waves might be able to couple directly into spacecraft harness and change logic states.

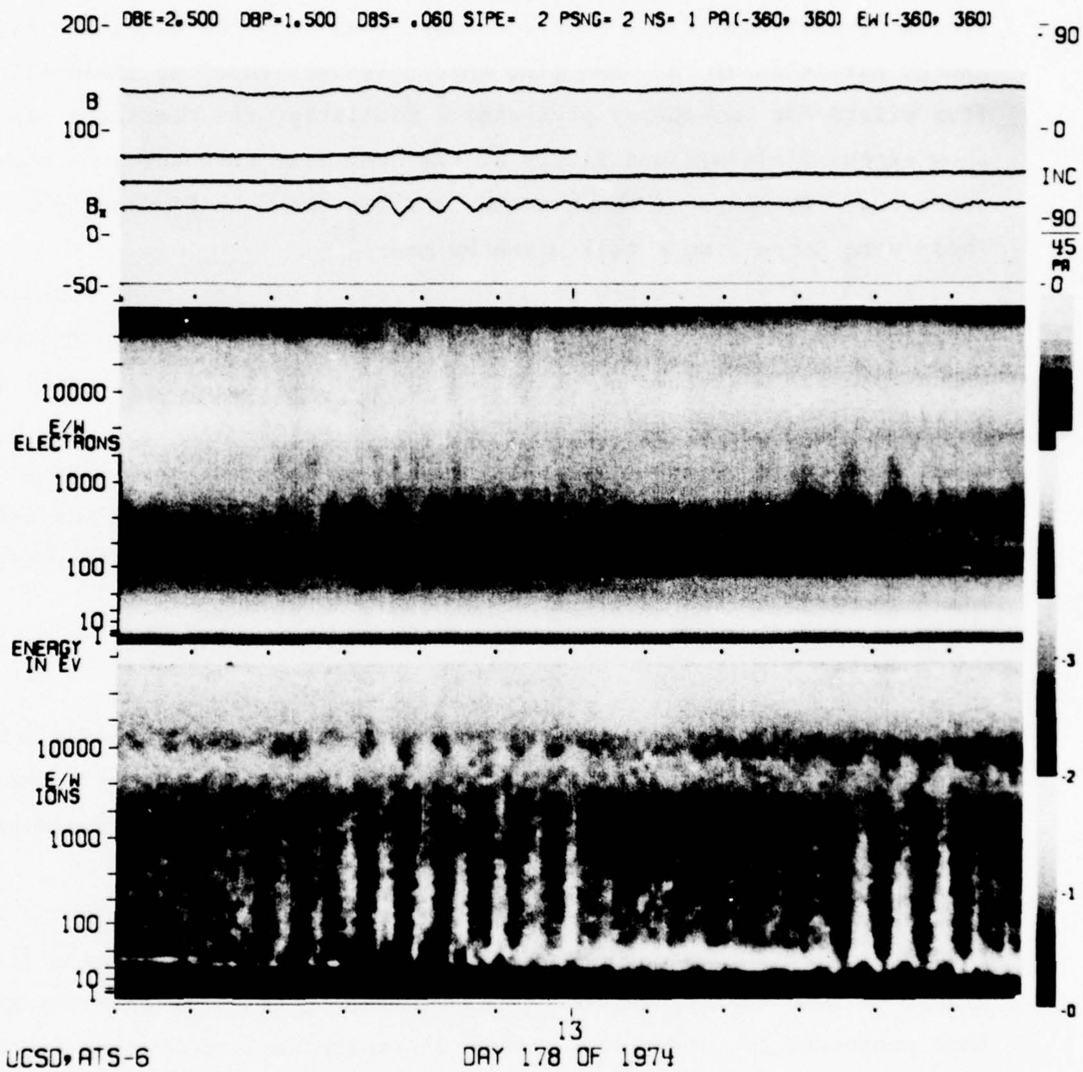

Figure 4. Spectrogram of Pc4 Event (DeForest et al.)

3.3 FIELD ALIGNED FLUXES

One of the outstanding discoveries of ATS-6 is the occasional presence of intense field-aligned fluxes of electrons.[18] Detailed studies of the general anisotropy are still in progress, but the situation at present is that a well-developed loss cone can exist for high-energy particles at the same time that a "source cone" of field-aligned flux exists for low-energy particles. Similarly, the electrons can show excess field-aligned fluxes at the same time that the ions show a loss cone. Examples of these situations are shown in Figures 5-8. These were taken from a talk given by Mauk.[19]

We do not yet know how these anisotropies fit into magnetospheric dynamics. Even worse, we are unable to quote good statistics on their occurrence since whether they are observed or not is in great part an artifact of the orbit and orientation of the detector.

However, we do know[20] that the fluxes of field-aligned electrons can at times completely dominate the charging in cavities at the ends of spacecraft. This is true even though the total anisotropic component is small compared to the isotropic component.

3.4 COMMENTS

We are still finding new plasma phenomena at geosynchronous orbit. We understand the overall patterns fairly well and are making progress on understanding such things as waves. But one must always remember that this is a very complex environment.

When certain classes of operating anomalies fail to correlate with substorm injections or other indications of activity, the reason might simply be that the spacecraft was inadvertently oriented in a manner that protected it. Next time around the spacecraft might slew in orbit or the magnetic field might tip. Then field-aligned fluxes might have access to more sensitive components and thereby produce an anomaly.

A convenient comparison is to say that substorms are like the earthly thunderstorms that we can predict and understand reasonably well. Many of these unusual events are like tornados. We understand a little about them. We know they are associated with larger events, and they are potentially dangerous.

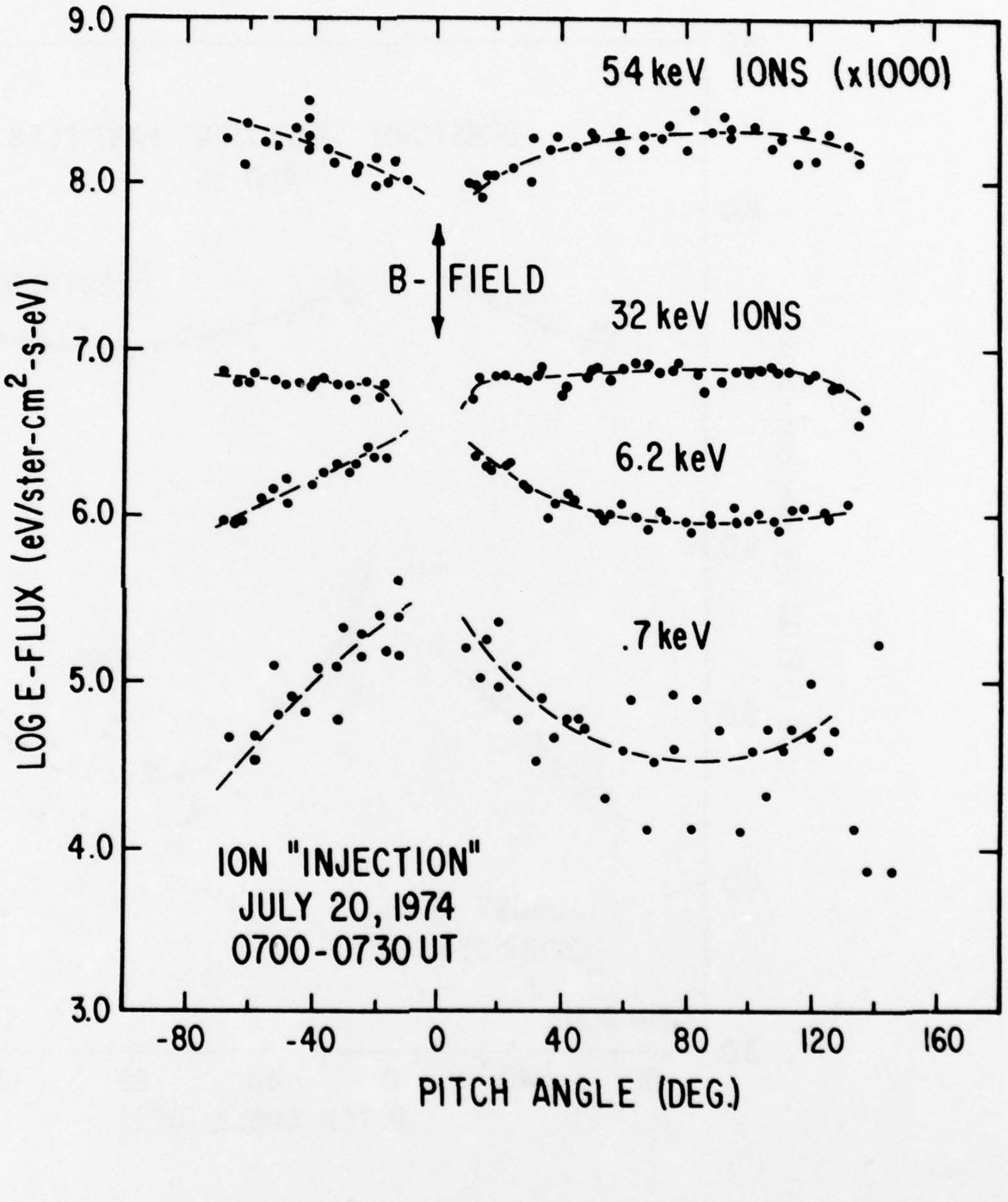

Figure 5. Particle Anisotropies from ATS-6 (Mauk)

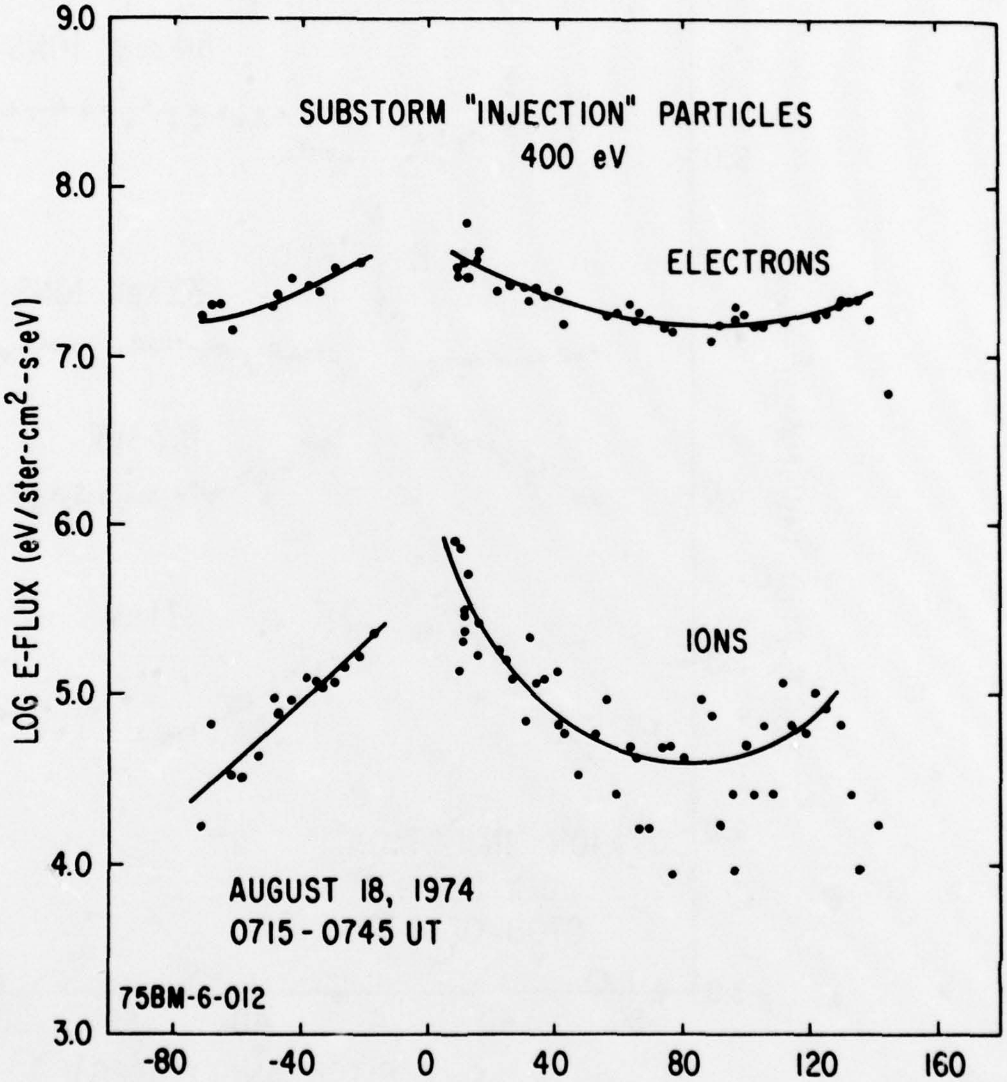

Figure 6. Particle Anisotropies from ATS-6 (Mauk)

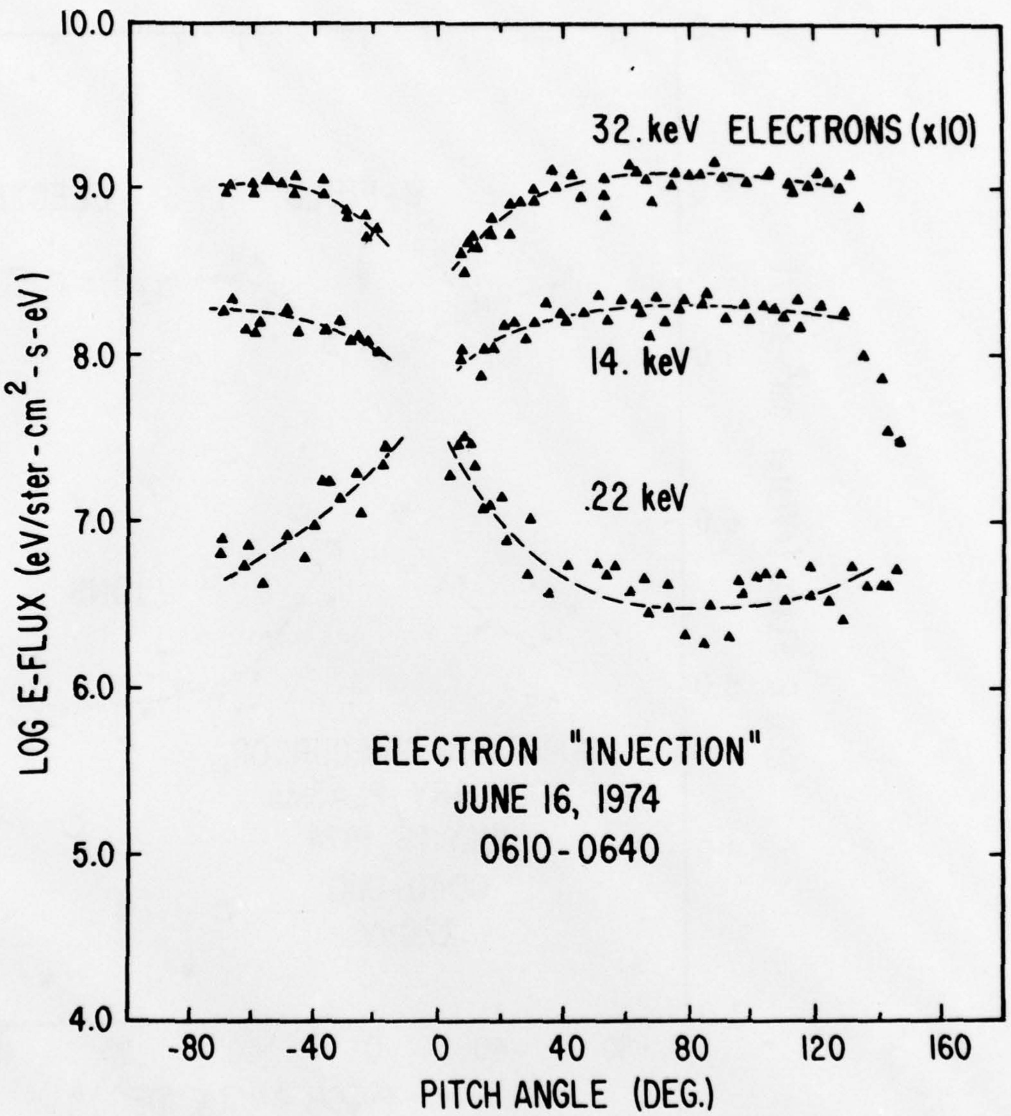

Figure 7. Particle Anisotropies from ATS-6 (Mauk)

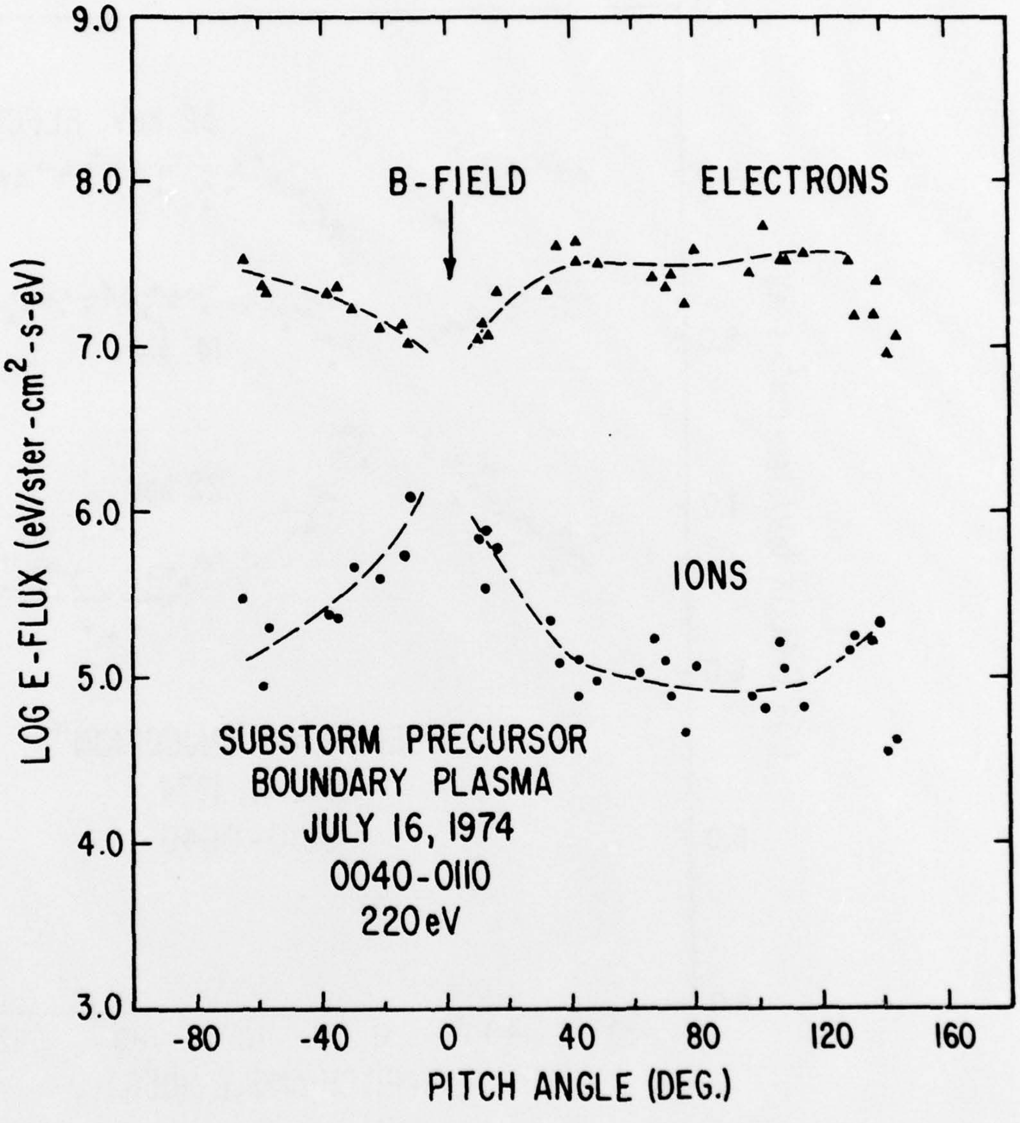

Figure 8. Particle Anisotropies from ATS-6 (Mauk)

4.0 MODEL

The general problem of modelling this environment is quite difficult because of the inherent complexity of plasma interactions. One can easily name 17 different independent parameters that would have to be specified as a function of time to represent the environment. And that would be possible only by assuming a Maxwellian distribution for the various constituents.

The particular problem of providing a simple model to the spacecraft designer is also difficult since blindly specifying the worst case for all parameters could result in severe overdesign and waste.

The initial model proposed in this study was to select representative days from the five years of available ATS-5 data and add to this a model of field-aligned fluxes and low-energy plasmas that had been derived from the more recent ATS-6 data. This approach has the benefit of providing users with real data suitable for computer modelling in a relatively quick and low cost way.

Six days have been picked which have examples of many different types of activity.

However the potential users at this conference have expressed a desire for an even simpler environmental specification even though they realize it would not be as definitive. Therefore we are currently reassembling the available data to assemble such a simplified model in a timely fashion.

One observation that can be of use is shown in Figure 9. Data for a whole year were scanned to find those substorms which occurred in the immediate vicinity of ATS-5. Then the measured energy flux was plotted against the number flux. Far from being random, the points are well-ordered, if somewhat confusing. A slope of 1 on the figure would indicate a constant temperature. That is definitely not the case, but no suitable explanation for the shape has yet been proposed. Still we can fit a curve to these points and eliminate at least one variable in the model.

4.1 OMNIDIRECTIONAL ELECTRON FLUXES

ATS-5 plasma data was scanned for the whole year of 1970. This year was chosen because the instrument operated perfectly for the whole

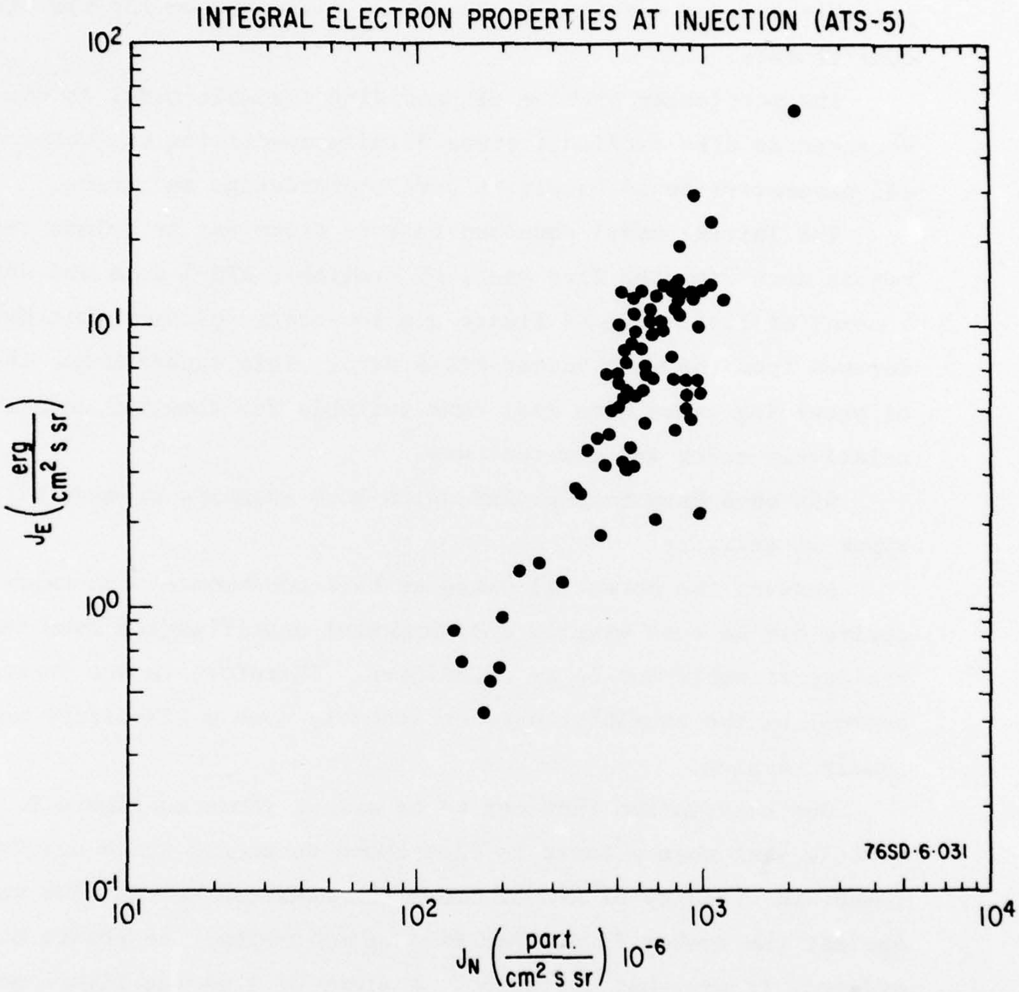

Figure 9. Energy Flux vs Number Flux of Electrons at Geosynchronous Orbit

year with no sign of degradation. The relative occurence of number fluxes greater than any amount was computed and is shown in Figure 10. The data included in the figure are not all injections, but only those that occurred in the immediate vicinity of the spacecraft and hence did not have time to disperse by gradient drifting before the measurement was made. This subset of the total injection events was chosen in order to simplify the ordering of the data, and to measure as nearly as possible the unmodified plasma.

The smallest measured flux in Figure 10 is actually 1.5×10^{-4} particles/cm^2sr sec. The curve has arbitrarily extended to 100% at 1.0×10^{-6}particles/cm^2sr sec. The curve itself has a steeply falling break with a slight tail. From this we can define two relevant fluxes. The first is the level of a typical exposure. A spacecraft exposed will certainly be exposed to fluxes of this level. The second relevant flux is obtained by extrapolating the curve to zero occurrences. This yields a flux which is the absolute maximum that a spacecraft might be expected to experience during a one year flight at geosynchronous orbit. (Strictly speaking, it is the maximum flux observed during this particular phase of the solar cycle. However, a less detailed scan of the next two year's data indicates that this does seem to be a good upper limit.) These fluxes are:

1. 10^{-3}particles/cm^2sr sec for the typical exposure experienced.
2. 10^{-2}particles/cm^2sr sec for the extreme exposure experienced.

While the second limit is somewhat arbitrary, it should be a safe design limit. The probability of exceeding 10^{-2}in a year is probably less than 1 part in 10^4. This is based on both the ATS-5 data as indicated above, and on subsequent review of the ATS-6 data up through 1976.

With these two limits, we can use the functional relation implied in Figure 9 to estimate to corresponding typical and extreme energy fluxes. The best way of doing this is to take the values indicated by the top of the envelope of data points rather than the root mean square value. This gives an upper limit. The best values are:

1. 16.erg/cm^2sec sr for the typical exposure
2. 770.erg/cm^2sec sr for the extreme exposure

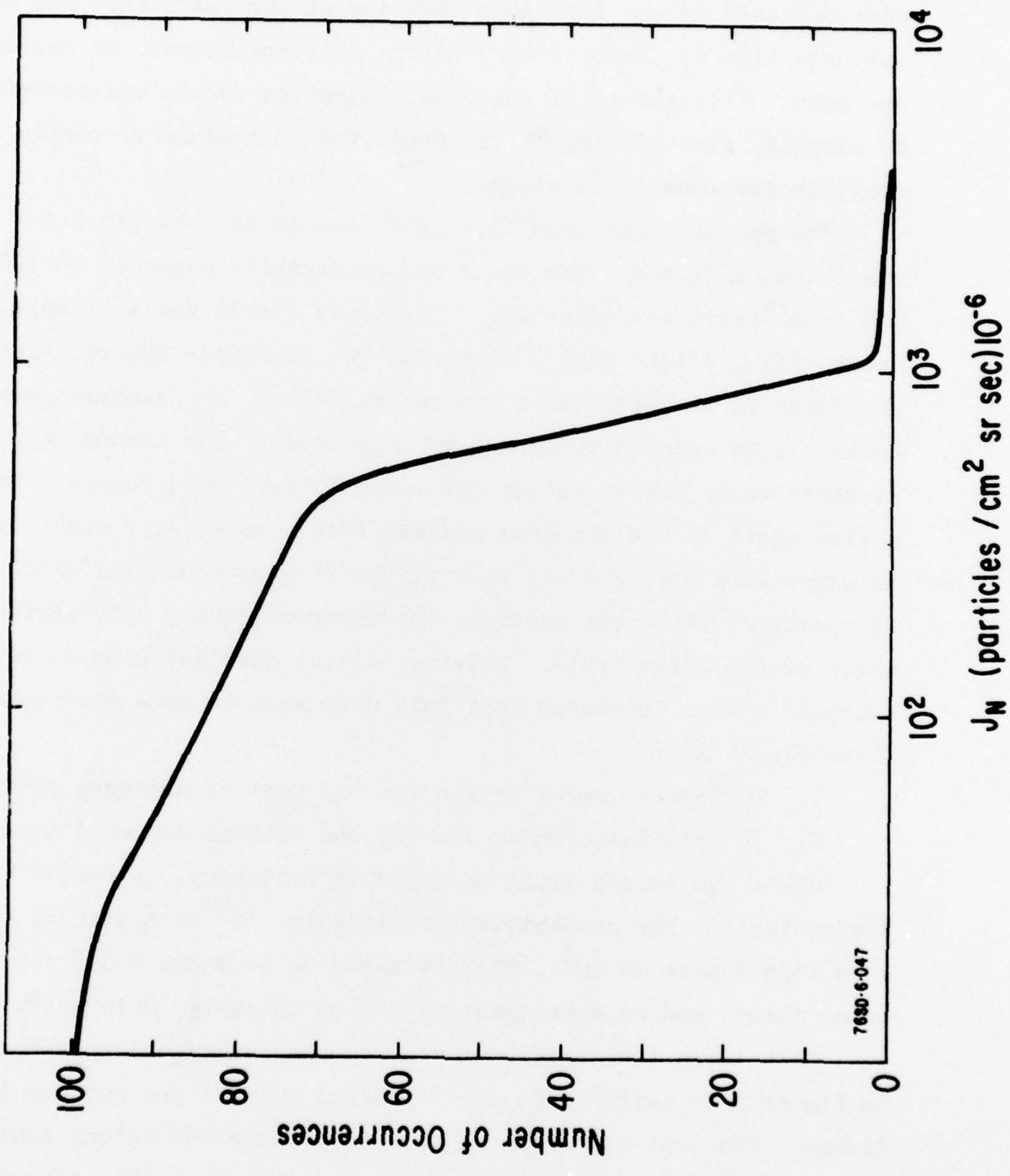

Figure 10. Relative Occurrence Frequency vs Number Flux of Electrons at Geosynchronous Orbit

Finally we can derive from these two pairs of numbers the average energy for each case by simply dividing:

1. 16 keV for the typical case
2. 77 keV for the extreme case

Only the electron flux is considered here because the worst case of differential charging on a space vehicle probably comes when the electron flux is neutralized not by the corresponding injected ion flux, but by low energy ions which have their origin much lower in the ionosphere. The electron flux also dominates in the case where the sunlit side of the vehicle is held at near zero potential by the emission of photo-electrons while the dark side is bombarded by the injected plasma. In fact, this last case places the maximum electrical stress on the exposed surfaces.

4.2 UNIDIRECTIONAL ELECTRON FLUXES

We do not as yet have a completely satisfactory description of field-aligned fluxes of electrons. The best we can do is to scan the available data from ATS-6 keeping in mind that the duty cycle on sampling is low and that certain orbital artifacts might be present (i.e. the orientation of the spacecraft might increase the probability of detecting field-aligned fluxes at certain local times).

The total flux in a field aligned event is small compared to the total flux hitting the surface of a spacecraft. Very likely the main reason for studying these non-isotropic fluxes is to see how they effect the potentials on the inner surfaces of cavities that might be exposed to field-aligned fluxes more than to the omnidirectional component. Therefore we can use a relatively simple model. Since we have already shown that ions can be deficient in the classical "loss" cone, we will assume here that no ions at all are field-aligned. The electrons will be assumed to be a delta function in energy with some total flux which is uniform across the 3.5° wide loss cone. With these assumptions, we can use the work cited earlier (reference 20) for typical and worse cases.

1. Typical case

   Flux = 2×10^{9} electrons/cm^{2}sec

   Energy = 220 electron volts

2. Extreme case

Flux = 3.5×10^8 electrons/cm^2sec

Energy = 2200 electron volts

4.2 UNIDIRECTIONAL ELECTRON FLUXES

The user is warned that the statistics on the occurrence of these field-aligned fluxes is still poor. The numbers above are based on 20 events. The second event was named as worse case because of the higher energies. A more conservative approach might be to assume both the higher flux and higher energy occur simultaneously even though this has not been observed.

4.3 USE OF THIS MODEL

The numbers presented in this section are not meant to represent an environmental specification in any final sense. They are meant to give typical and maximum fluxes that might reasonably be expected so that designers can at least make a start without utilizing a full computer simulation. Special events such as rapid flows, waves, or fluxes of heavy ions will be considered in the more developed models to follow. The numbers presented here might be pessimistic in the sense that future models might be somewhat lower in total flux to a given surface over a long period of time, but the upper limits of fluxes will probably continue to be accepted as characteristic of short events (i.e. intense injections where the peak flux is reached and decays away in times of order one-half hour or less). As mentioned above, the statistics for the omnidirectional component of the flux are much better than those for the field-aligned component. Therefore higher fluxes of non-isotropic electrons might be detected in the future. These quoted here are the highest seen to date.

VII. PERSONNEL

A list of personnel who contributed to the work reported here is given below.

1. Sherman DeForest
   Associate Research Physicist
2. Elden C. Whipple, Jr.
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3. Gerald Peters
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In addition to those who were supported by this contract, the following contributed by fruitful discussion.

1. Prof. C. E. McIlwain, UCSD
2. Dr. C. Pike, AFGL
3. Lt. H. Garrett, AFGL
4. C. Purvis, NASA Lewis
5. B. Bartlett, NASA GSFC
6. Dr. A. Wilson, S3
7. Dr. I. Katz, S3

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